Design of Pi Controller To Minimize The Speed Error of D.C. Servo Motor

Sanjay Singh, Dr. A. K. Pandey, Dipraj

Abstract— This study present efficient method for speed control of a D.C. Servo Motor using PI controller. Design of a PI controller requires minimizing the error. The experimental is used to obtain the transfer function to design the PI controller. The effectiveness of the design is validated using MATLAB/Simulink. This new design method gives us a simple and powerful way to design a speed controller for a servo – motor**.** This paper identifies and describes the design choices related to a PI controller for a D.C. servo motor. D.C. servo motor is also variable speed drive, and paper presents variable speed with minimizing speed error.

Index Terms— Control System, Proportional-Integral (P-I) controller, Speed control, Error control, Modeling of System, Separately Excited D.C. Servo Motor, MATLAB / SIMULINK.

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1 INTRODUCTION

Everyone recognizes the vital role played by electrical motors in the development of industrial systems. There are five major types of D.C motors in general use, which are the separately excited D.C motor, the shunt D.C motor, the permanent – magnet D. motor, the series D.C motor and the compound D.C motor. The D.C machine is the first practical device to convert electrical power into mechanical power, and vice versa. Inherently straightforward operating characteristics, flexible performance and efficiency encouraged the use of D.C motors in many types of industrial drive application. Most multi-purpose production machines benefit from adjustable speed control, since frequently their speeds must change to optimize the machine process or adapt it to various tasks for improved product quality, production speed. The Proportional-Integral (P-I) controller is one of the conventional controllers and it has been widely used for the speed control of dc motor drives [3]. The major features of the P-I controller are its ability to maintain a zero steady-state error to a step change in reference. Due to sudden change in load torque and the sensitivity to controller gains K_I and K_P have been proposed for the speed control of dc motors [8].

2 LITERATURE REVIEW

2.1 Servo Motor Description

Electric motors can be classified by their functions as servomotors, gear motors, and so forth, and by their electrical configurations as DC (direct current) and AC (alternating current motors. Servomotor is a motor used for position or speed control in closed loop control systems. The requirement from a servomotor is to turnover a wide range of speeds and also to perform position and speed. DC servo motors have been used generally at the computers, numeric control machines, industrial equipments, weapon industry, and speed control of alternators, control mechanism of full automatic regulators as the first starter, starting systems quickly and correctly [4] [6]. Some properties of DC servo motors are the same, like inertia, physical structure, shaft resonance and shaft characteristics, their electrical and physical constants are variable. The velocity and position tolerance of servo motors which are used at the control systems are nearly the same. It has implemented proportional integral, fuzzy logic and adaptive neuro fuzzy inference system respectively at the variable working situations to the simulation model which has prepared at the Matlab programmers for improvement the servo motor performance.

2.2 Proportional plus Integral Controller Description

Proportional plus Integral (PI) controllers are widely used in industrial practice for more than 60 years. The development went from pneumatic through analogue to digital controllers, but the control algorithm is in fact the same. The PI controller is standard and proved solution for the most industrial application. The main reason is its relatively simple structure, which can be easily understood and implemented in practice, and that many sophisticated control strategies, such as model predictive control, are based on it. An application with large speed capabilities requires different PI gains than an application which operates at a fixed speed. In addition, industrial equipment that are operating over wide range of speeds, requires different gains at the lower and higher end of the speed range in order to avoid overshoots and oscillations. Generally, tuning the proportional and integral constants for a large speed control process is costly and time consuming. The task is further complicated when incorrect PI constants are sometimes entered due the lack of understanding of the process. The control action of a proportional plus integral controller is defined as by following equation:

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$$u(t) = K_p\, e(t) + K_i \int_0^t e(t)dt \qquad (1)$$

Where:

$u(t)$ is actuating signal.
$e(t)$ is error signal.
K_p is Proportional gain constant.
K_i is Integral gain constant.

The Laplace transform of the actuating signal incorporating in proportional plus integral control is

$$U(s) = K_p\, E(s) + K_i\, \frac{E(s)}{s} \qquad (2)$$

The block diagram of closed loop control system with PI control of D.C. Servo Motor System is shown in Figure 3.1. The error signal E(s) is fed into two controllers, i.e. Proportional block and Integral block, called PI controller. The output of PI controller, U(s), is fed to D.C. Servo Motor System. The overall output of D.C. drive, may be speed or position, C(s) is feedback to reference input R(s). Error signal can be remove by increasing the value of K_p, K_i.

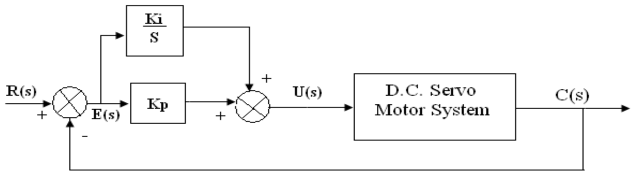

Fig.1. Block diagram of PI Control Action with D.C. Servo Motor System

However the feedback of control system is unity. If increases the gain of feedback the stability of system is decreases.

3 MODELING OF D.C. SERVO MOTOR

3.1 Mathematical Modeling of D.C. Servo Motor System

Fig.2. represented the servo motor model. Let's consider:-
$E_a\ (t)$ =Input voltage
$i_a\ (t)$ =Armature current
R_a = Armature resistance
L_a = Armature inductance
$E_b\ (t)$ =Back e.m.f
T_m= Developed Torque
ω_m =Motor angular velocity
J=Motor moment of inertia
B=Viscous friction coefficient
K_b=Back e.m.f constant
K_T=Torque constant

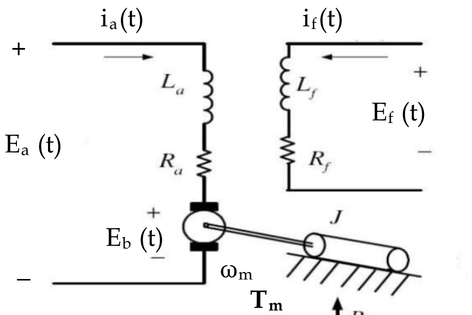

Fig.2. Separately Excited DC Motor

Here, the differential equation of armature circuit is-

$$E_a\ (t) = R_a.i_a\ (t) + L_a.\frac{di_a\ (t)}{dt} + E_b\ (t) \qquad (1)$$

The Torque equation is-

$$T_m\ (t) = J.\frac{d\omega_m\ (t)}{dt} + B.\omega_m\ (t) \qquad (2)$$

The torque developed by motor is proportional to the product of the armature current and field current i.e.

$$T_m\ (t) = K_f.i_f.i_a \qquad (3)$$

Where, K_f is constant.

In armature – controlled D.C. motor the field current (i_f) is kept constant i.e.

$$T_m = K_T.i_a \qquad (4)$$

Where, $K_T = K_f.i_f$ is torque constant.

The back e.m.f. of motor is proportional to the speed i.e.

$$E_b\ (t) = K_b.\ \omega_m \qquad (5)$$

Where, K_b is back e.m.f. constant.

In order to create the block diagram of system initial conditions are zero and Laplace transform is implemented to the equations. i.e.

$$E_a\ (s) = R_a.I_a\ (s) + sL_a.I_a\ (s) + E_b\ (s)$$

$$I_a\ (s) = \frac{Ea\ (s) - E_b\ (s)}{sL_a + R_a} \qquad (6)$$

$$T_m\ (s) = sJ.\omega_m(s) + B.\omega_m\ (s)$$

$$\omega_m\ (s) = \frac{T_m(s)}{sJ + B} \qquad (7)$$

$$T_m(s) = K_T.I_a(s) \qquad (8)$$

$$E_b\ (s) = K_b.\ \omega_m(s) \qquad (9)$$

3.2 Block-diagram

The forward path blocks are the transfer function of following:

$$\frac{I_a\ (s)}{E_a\ (s) - E_b\ (s)} = \frac{1}{sL_a + R_a}$$

$$\underline{T_m(s)} = K_T$$
$$I_a(s)$$

$$\frac{\omega_m\ (s)}{T_m(s)} = \frac{1}{sJ + B}$$

The feedback path block is the transfer function of following:

$$\frac{E_b\ (s)}{\omega_m\ (s)} = K_b$$

Fig.3. only show the block diagram of armature controlled

D.C. Motor.

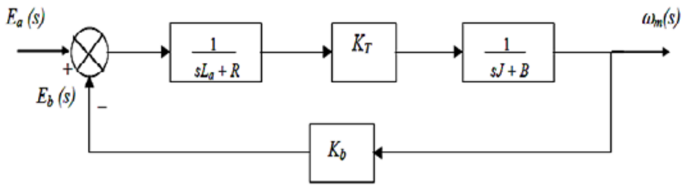

Fig.3. Block-Diagram of Separately Excited DC Motor

4 SIMULATION

4.1 Simulink Model

Fig.4 shows the simulink model of D.C. Servo Motor system. In this model two PI controllers is used. First PI controller is used for control the speed and second PI controller is use to control the armature current. The speed response at different reference input 110V to 220V and 110V to 55V as shown in Fig.5 and Fig.7 respectively. And corresponding minimized speed error as in Fig.6 and Fig.8.

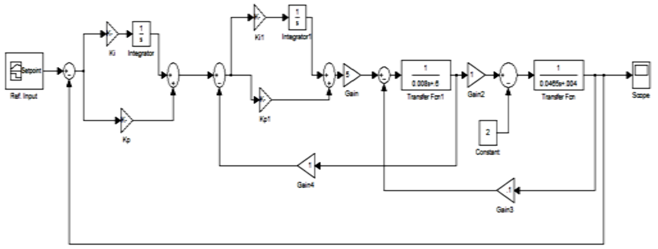

Fig.4. Simulink Model of D.C. Servo Motor

4.2 Responses

4.2.1 Speed Response (*Ref. input 110V to 220V*)

The speed response of D.C. servo motor is shown below. The rated reference input 110V for 5 second and then suddenly increase input up to 220V for 4 second, the corresponding speed is found. The value of proportional gain and integral gain is adjusted to minimized overshoots, rise time, peak time and settling time. Due to minimization of transient specifications the system becomes fast and steady state easily occurs.

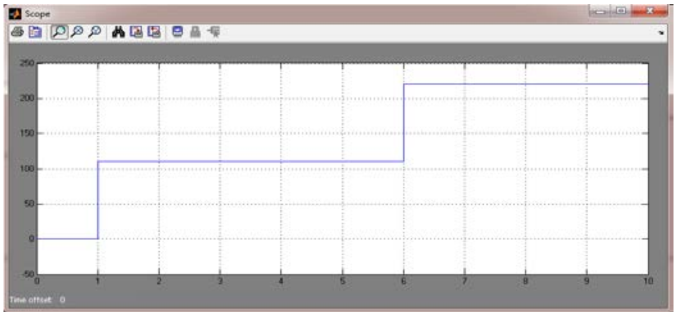

Fig.5. Speed Response of D.C. Servo Motor

4.2.2 Speed Error Response (*Ref. input 110V to 220V*)

The minimized seed error response at 110V to 220V shown in Fig.6. From Fig.5 and Fig.6, when reference input increase from 0V to 110V, the speed error increase 0V to 110V. But when speed become constant (become steady state) the error slightly fall and become zero. When reference input increase from 110V to 220V, the speed error increase 0V to 110V. But when speed become constant (become steady state) the error slightly fall and become zero.

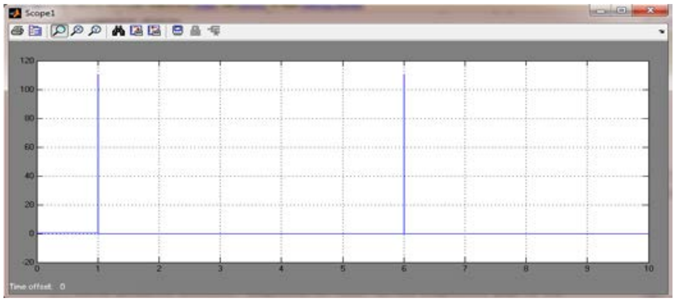

Fig.6. Speed Error of D.C. Servo Motor

4.2.3 Speed Response (*Ref. input 110V to 55V*)

The speed response of D.C. servo motor is shown below. The rated reference input 110V for 5 second and then suddenly decrease input up to 55V for 4 second, the corresponding speed is found. The value of proportional gain and integral gain is adjusted to minimized overshoots, rise time, peak time and settling time. Due to minimization of transient specifications the system becomes fast and steady state easily occurs.

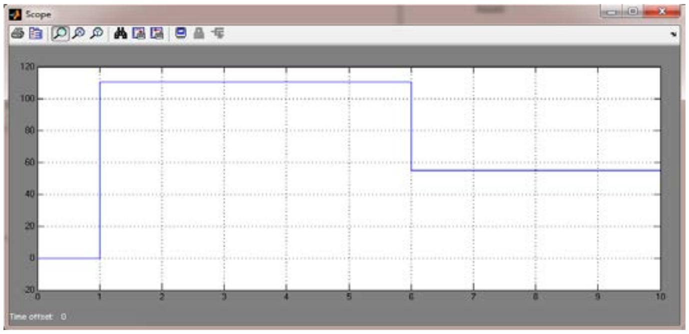

Fig.7. Speed Response of D.C. Servo Motor

4.2.4 Speed Error Response (*Ref. input 110V to 55V*)

The minimized seed error response at 110V to 55V shown in Fig.8. From Fig.7 and Fig.8, when reference input increase from 0V to 110V, the speed error increase 0V to 110V. But when speed become constant (become steady state) the error slightly fall and become zero. When reference input decrease from 110V to 55V, the speed error decrease from 0V to 55V. But when speed become constant (become steady state) the error slightly increase and become zero.

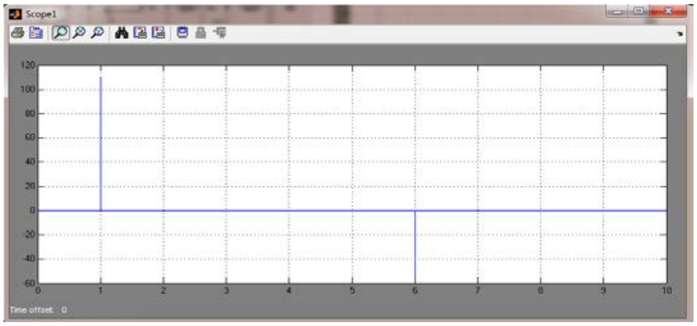

Fig.8. Speed Error of D.C. Servo Motor

5 CONCLUSION

A PI controller for a D.C. servomotor has been studied. The performance of PI controller was evaluated by simulation. The controller gain was adjusted to obtain minimized error responses. The results show significant improvement in maintaining performance of approximate zero overshoot, minimum stabilizing time.

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4.1 D.C. Servo Motor Parameter

The motor used in this experiment is an 110V D.C. motor with no load speed of 4050 rpm.

Parameter Value
R-resistance 0.6 Ω
L-inductance 8 mH
J-moment of inertia 0.0465 kg.m^2
K_t -torque constant 0.052 Nm/A
K_b-electromotive force constant 0.1 V/rad/s
B-viscous friction coefficient 0.004 N.m/rad/s